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Geology and Mineral Resources

of the

Cache Creek-Rocky Creek

Wilderness Study Area

By

Larry Vredenburgh
August, 1981

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SUMMARY

The Cache Creek-Rocky Creek WSA contains deposits or occurrences of mercury-gold, asbestos, placer chromite, gemstones, magnesite and sand and gravel. There has been production of mercury from within the area and there is potential for production of gold. Recent development work at the Knoxville mercury mines has delineated a major gold deposit which may extend into the WSA. Claims have been staked in the WSA to explore for a possible extension of the gold mineralization at Knoxville.

Natural gas seeps occur within the WSA, and there is potential for oil and gas. There is potential for the production of electrical energy from geothermal sources at Wilbur Springs and the geothermal reservoir may extend into the WSA.

INTRODUCTION

The Cache Creek-Rocky Creek Wilderness Study Area (WSA) is located in the Coast Range of California, east of Clear Lake, south of Wilbur Spring, and north of Knoxville (see Figure 1). It encompasses 33,582 acres and embraces Buck Mountain, Round Mountain, Little Blue Ridge and Brushy Sky High. Portions of T.13N., R.5 and 6W. and T.12N., R.5W.MDM are within this area. It is located within the Clear Lake Resource Area of the Ukiah District.

Access into the WSA is restricted to a jeep trail from Highway 20 to Cache Creek across the central part of the area. During a fire in the summer 1981, a fire break was bulldozed from Bear Spring to the north for a distance of about two miles.

PREVIOUS WORKS

The first workers to map and describe the area were Becker (1888) and Forstner (1903) who studied the mercury resources of the area. Lawton (1956) mapped and described in detail the geology of the eastern portion of the Cache Creek-Rocky Creek WSA. A condensation of James Brice's PhD thesis of 1950 from the University of California, Berkeley, was published in 1953 by the California Division of Mines. The published thesis is a reconnaissance of the western part of the WSA. Other workers in the area include Moisseeff (1966), who mapped and described the Wilbur Springs district; Averett (1945), who described and mapped the Knoxville district; and Christine Carlson (1981), who recently mapped and described an area south and east of Wilbur Springs.

In 1972 the U.S. Geological Survey began in-depth studies of the Geysers geothermal field. The results of these studies were published in McLaughlin and Donnelly-Nolan (1981).

SCOPE OF REPORT

This report was written to identify the mineral resources of the Cache Creek-Rocky Creek WSA. It was written entirely from published and unpublished literature sources and from personal and written communication with persons familiar with the area. No time was spent in the field. Because of the recent gold discoveries at Knoxville and the presence of a mercury-gold deposit deep within the WSA, a section discussing various aspects of this type of ore deposit has been included.

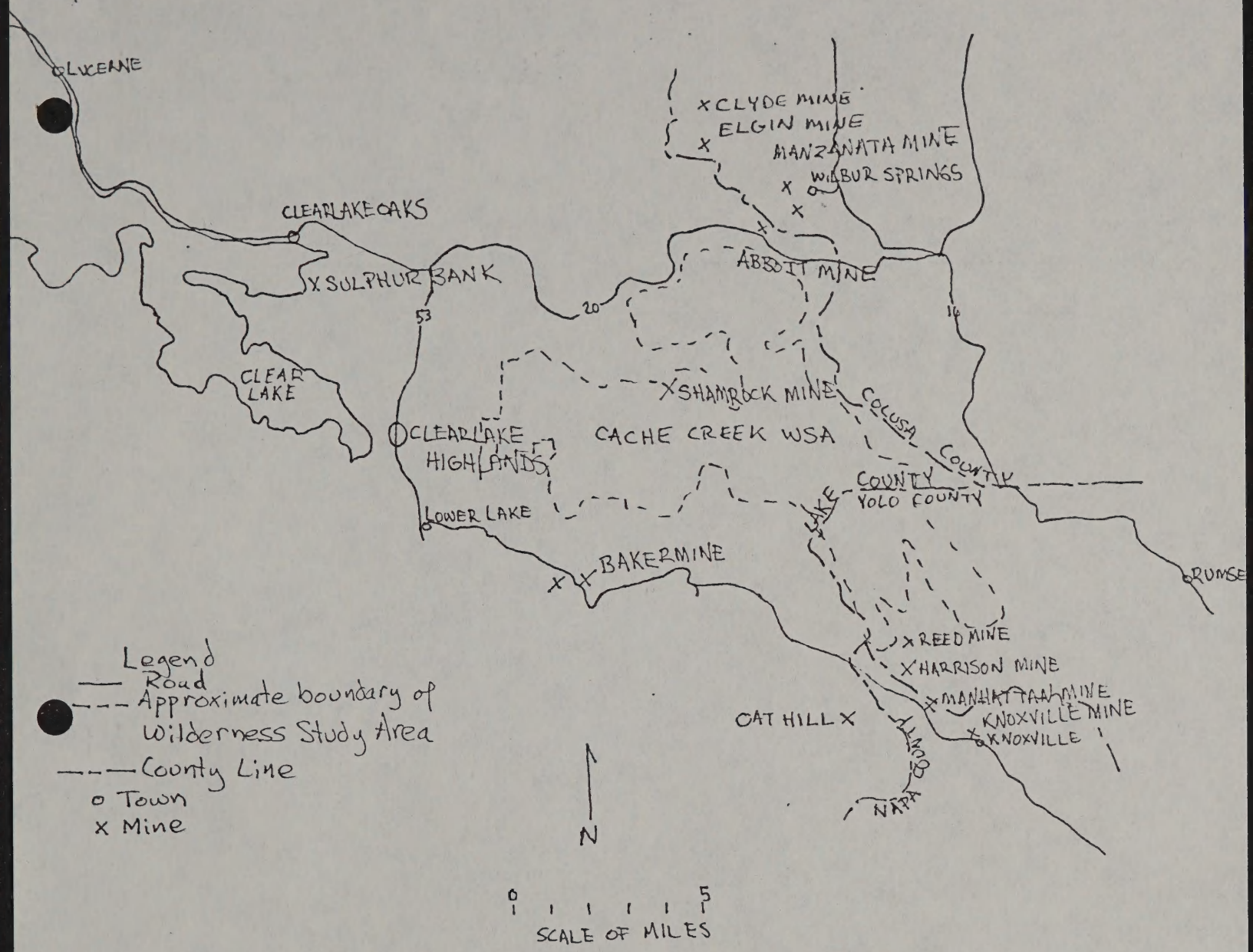

Figure 1

Index Map - showing location of gold bearing mercury deposits.

RELIEF AND DRAINAGE

The highest elevation in the area is the 3,196 foot high Brushy Sky High. The lowest is at about 800 feet, located on Cache Creek. The ridges are generally formed by units of sandstones or serpentine which are more resistant to erosion than the adjacent shales in this area.

Cache Creek and its tributaries drain an area of about 750 square miles and flow through the WSA. Almost all of the streams in the area are tributary to Cache Creek. Cache Creek appears to be a superimposed stream whose intrenched meanders were formed on an earlier preexistent flood plain.

ACKNOWLEDGEMENTS

I would like to thank the following persons who helped in the preparation of this report: Susan Skinner, BLM Ukiah District Office; Edmond Lawrence, consultant; Christine Carlson, GS Menlo Park; Robert McLaughlin, GS Menlo Park; Don White, GS Menlo Park; M.C. Smith, Claimant; Steve Graham, Stanford University; Foster Howland, Resource Exploration.

GEOLOGY

According to McLaughlin (1981):

> The northern California Coast ranges east of the San Andreas Fault...consist mainly of two approximately coeval units now separated by a great thrust (Bailey and others, 1970). The upper plate of the Coast Range thrust consists of a fragmented ophiolite complex of Late Jurassic Age (the Coast Range ophiolite), considered to represent oceanic crust (Bailey and others, 1970; McLaughlin and Pessagno, 1978) overlain depositionally by moderately deformed marine sedimentary rocks referred to as the Great Valley Sequence (Bailey and others, 1964). The Great Valley Sequence ranges in age from Late Jurassic to Late Cretaceous and consists of coarse ophiolite breccia or tuff near the base (McLaughlin and Pessagno, 1978) overlain by conglomerate, mudstone, and sandstone... The basal part of the Great Valley Sequence was largely derived from the depositionally underlying Coast Range ophiolite (McLaughlin and Pessagno, 1978).
>
> Rocks in the lower plate of the Coast Range thrust have been assigned to the Franciscan assemblage (or Franciscan Complex of Berkland and others, 1972) and consist of a heterogeneous assemblage of intensely deformed and mildly to moderately metamorphosed sandstone, shale, chert, and mafic igneous rocks. Serpentinite, limestone, amphibolite, eclogite and high grade blue schists are minor but significant constituents. Franciscan rocks and their equivalents are now known to extend along the

RELIEF AND DRAINAGE

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I would like to thank the following persons who helped in the preparation of this report: Susan Barney, BLM Ukiah District Office; Edward Lawrence, consultant; Christine Carlson, 55 Mono Park; Robert Kelsughlin, 55 Mono Park; Ann White, 55 Mono Park; M.C. Smith, Claimant; Steve Drake, Standard Chemicals; Foster Ishland, Resource Exploration.

GEOLOGY

Introduction to Kelsughlin (1981):

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Rocks in the lower plate of the Coast Range thrust have been assigned to the Franciscan assemblage (or Franciscan Complex of Hamilton and others, 1971) and consist of a heterogeneous assemblage of intensely deformed and mildly to moderately metamorphosed sandstone, shale, chert, and mafic igneous rocks. Serpentinite, limestone, amphibolite, eclogite and high grade schists are minor but significant constituents. Franciscan rocks and their equivalents are not known to extend along the

Pacific coast of North America at least from Baja California, Mexico, to southern Alaska (Jones and others, 1977). Initial deformation and metamorphism of these rocks apparently occurred in Cretaceous and early Tertiary time, as the result of oblique northeast-directed subduction and strike-slip.

The Great Valley Sequence which is extensively exposed in the WSA consists of about 40,000 feet of Jurassic and Cretaceous shale, siltstone, sandstone, and occasional lenses of conglomerate and limestone. The sequence has been divided into twelve formations (see Figure 2). In the southern part of the WSA at the north end of Morgan Valley, the Knoxville Formation of the Great Valley Sequence is in depositional contact with serpentine (Lawton, 1956).

Much of the mercury and all of the magnesite and asbestos in the Coast Ranges occurs in altered serpentine. Hot solutions rich in SiO_2 and CO_2 rising along faults have replaced serpentine by silica-carbonate rock, which consists of chalcedony, opal, quartz, magnesite and calcite.

There are three areas within the WSA where the Franciscan Complex is exposed, as shown on the 1:250,000 scale state geologic map. One area is near Wilbur Springs where it is in fault contact with serpentine. The other two are in Deadman Canyon. The contacts with serpentine are shown as depositional in Deadman Canyon, but the exact correlation of the sediments is in doubt, and they may actually be Great Valley sediments.

The Cache Formation of Pliocene age is located in the northeast part of the WSA. This formation consists of a sequence of lacustrine clay, silt, sand and gravel beds with minor amounts of tuff that are from 1,000 to 6,500 feet thick. Identified terrestrial vertebrate fossils recovered from this unit, suggest an age range of about 1.8 to 3.0 million years (Casteel and Rymer, 1981).

The Quaternary age Clear Lake Volcanics range in age from 2 million years (m.y.) to about 10,000 years and range in composition from basalt to rhyolite. None of these rock units are exposed within the WSA. Basalt does occur nearby at Quackenbush Mountain, near the junction of Ferris Canyon and Cache Creek, at the Knoxville mines, and on Coyote Peak near Wilbur Springs.

PALEONTOLOGY

The Cache Creek-Rocky Creek WSA contains a great diversity of vertebrate and invertebrate fossils. Lawton's (1956) thesis covering the north half of the Morgan Valley quadrangle and the south half of the Wilbur Springs quadrangle carefully details the fossils present in each formation. Casteel and Rymer's (1981) papers describe several fossil fish discovered in the Cache Formation. The reader is referred to these works for further details.

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The Great Valley Sequence which is extensively exposed in the WSA consists of nearly 40,000 feet of Jurassic and Cretaceous shale, siltstone, sandstone, and occasional lenses of conglomerate and limestone. The sequence has been divided into twelve formations (see Figure 2). In the southern part of the WSA at the north end of Kingman Valley, the Knoxville Formation of the Great Valley Sequence is in depositional contact with serpentine (Bailey, 1959).

Most of the serpentine and all of the magnesite and asbestos in the Coast Ranges occurs in altered serpentine. Hot solutions rich in SiO2 and CO2 rising along faults have replaced serpentine by silica-carbonate rock, which consists of chalcedony, opal, quartz, magnesite and calcite.

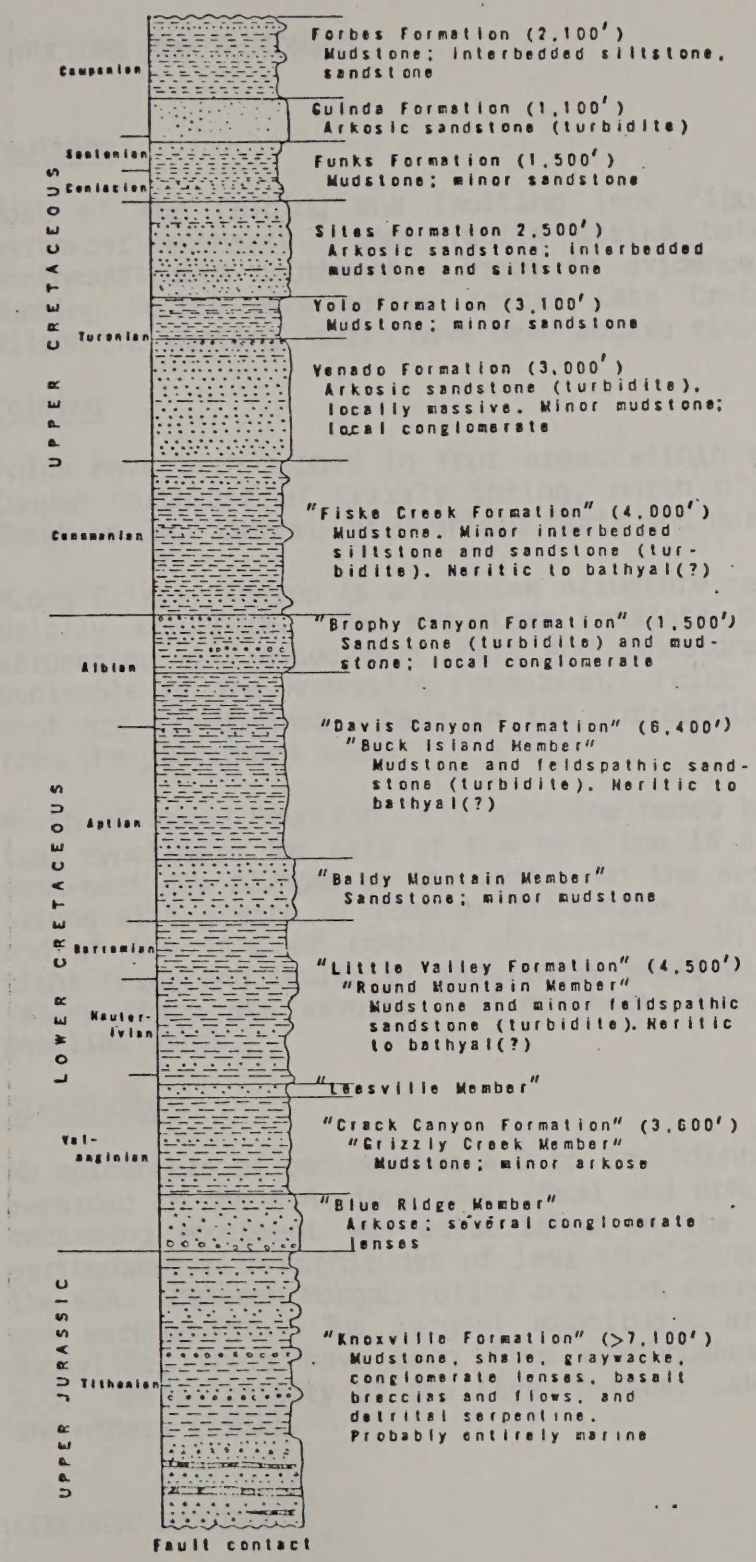
There are three areas within the WSA where the Franciscan Complex is exposed, as shown on the 1:250,000 scale state geologic map. One area is near Mount Shasta, where it is in fault contact with serpentine. The other two are in Goodwin Canyon. The contacts with serpentine are known as depositional in Goodwin Canyon, but, due great correlation of the sediments is in doubt, and they may actually be Great Valley sediments.

The Clear Creek Formation of Miocene age is located in the northeast part of the WSA. This formation consists of a sequence of lacustrine clay, silt, sand and gravel beds with minor amounts of tuff that are from 1,000 to 6,500 feet thick. Fossilized terrestrial vertebrate fossils recovered from this unit, suggest an age range of about 1.0 to 3.0 million years (Wagner and Wagner, 1981).

The Quaternary age Glass Mountain Volcanics range in age from 4 million years (m.y.) to about 10,000 years and lie in transition from basalt to rhyolite. Some of these rock units are exposed within the WSA. Basalt does crop out at Glassmountain Mountain, near the junction of Ferris Canyon and Cache Creek, at the Knoxville Ridge, and on Coyote Peak near Miller Springs.

INTRODUCTION

The Clear Creek-Rocky Creek WSA contains a great diversity of vertebrate and invertebrate fossils. Lawton's (1956) investigations the north half of and Kingman Valley quadrangle and the south half of the Miller Springs quadrangle certainly contain the fossils present in each formation. Carroll and Bennett's (1981) report describes several fossil fish discovered in the Cache Formation. The reader is referred to these works for further details.



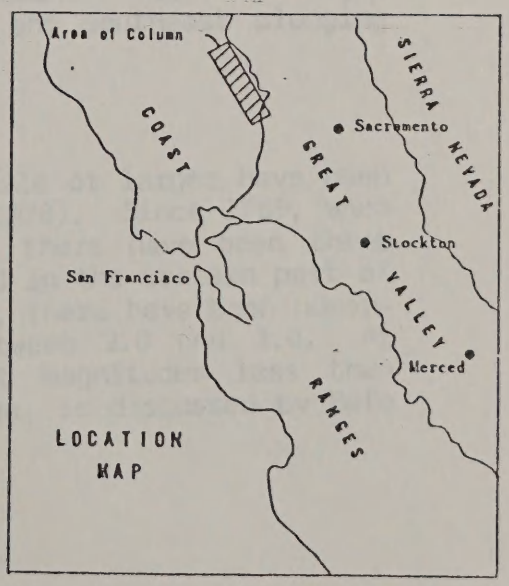
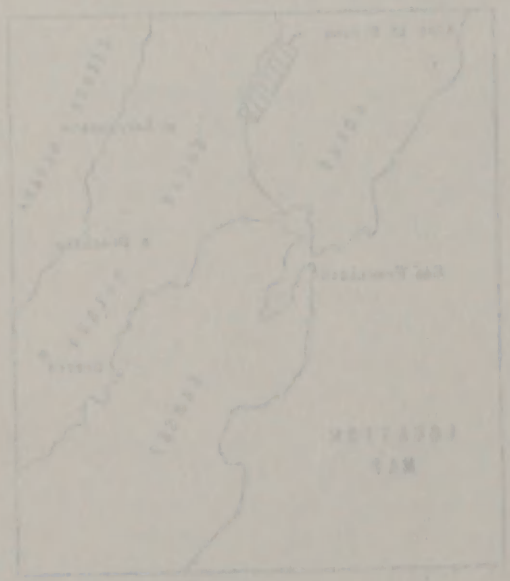


Figure 2

Northern Great Valley Sequence: composite column, Cache Creek to Wilbur Springs (from Page, 1966).



STRUCTURE AND TECTONICS

Faulting

Most of the folding and faulting (see Figure 3) in the area trends northwest-southeast. Some faults strike between north-south and north northeast-south southwest. There is evidence that the Bear Valley and Hunting Faults were active before Late Cretaceous time. The Kennedy, Wilson and Hunting Faults have been active since Pliocene-Pleistocene time.

Folding

Folds have been mapped in four areas within the WSA. These are Grizzly Canyon northeast of Grizzly Spring, north of Round Mountain from Brushy Creek to Jack Canyon, at Dunfield flats and northwest of Morgan Valley.

Along Grizzly Canyon is a complex structure named by Lawton (1956) as the Grizzly structure. The structure consists of three elongate masses of serpentine with associated shale and sandstone, all of which have pierced sediments of the Knoxville Formation. Folds associated with the piercement are ill-defined. Beds in the surrounding sediments dip gently away from the piercement mass.

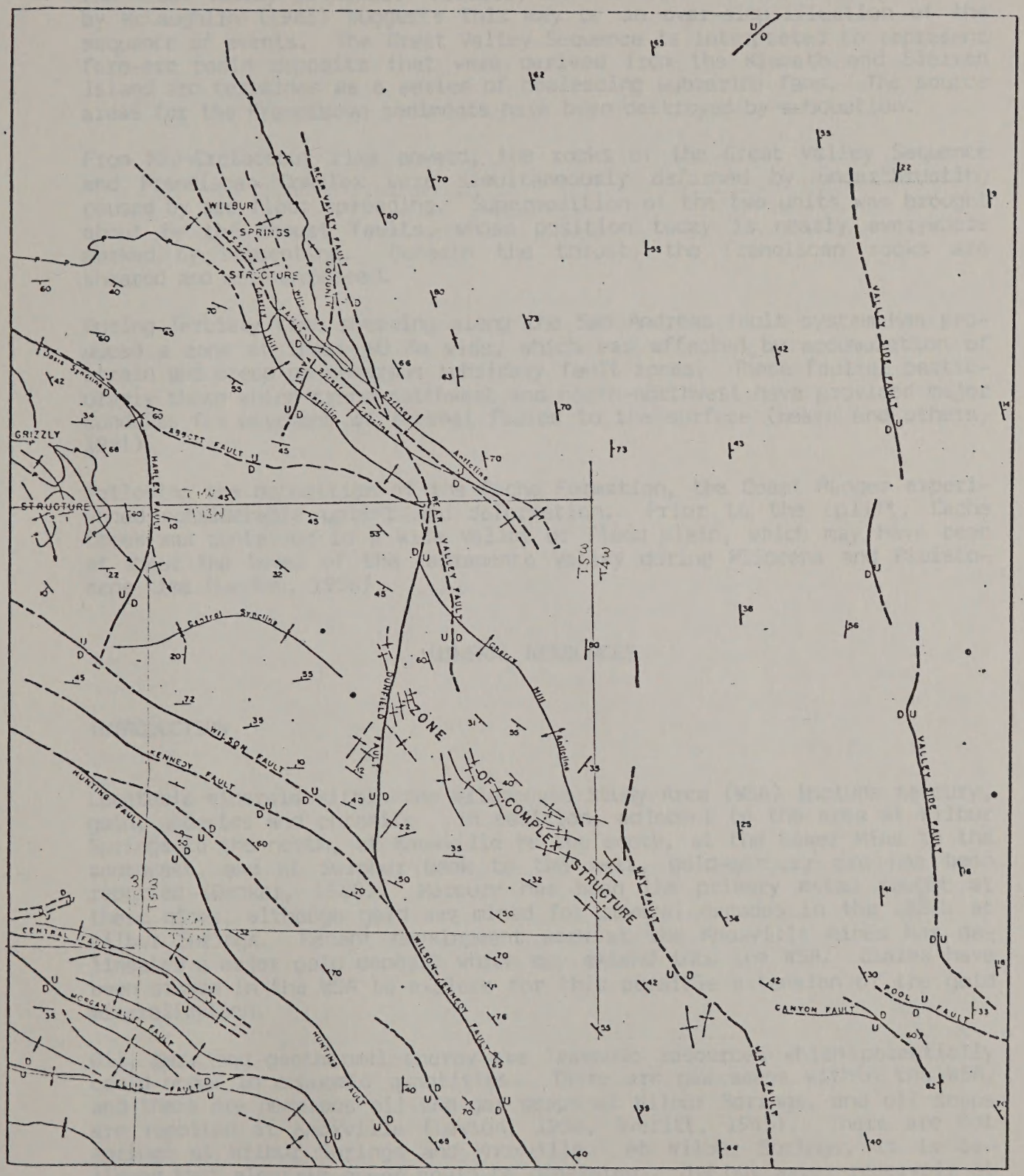
North of Round Mountain is a syncline named by Lawton (1956) as the central syncline. The axis of the syncline is sinuous, but trends generally east-west and plunges to the west. On the east, the axis of the syncline aligns with a zone of complex structures. Dunfield Flats is the western end of the zone of complex structures. In this zone, there are small tight folds and faults of apparently small displacement. North of Morgan Valley there are several west-northwest trending and southeast plunging parallel folds.

Siesmicity

No epicenters of earthquakes 4.0 on the Richter Scale or larger have been recorded in the WSA since 1900 (Real and others, 1978). Since 1969, when recording equipment was established in the area, there have been three earthquakes with magnitudes of less than 2 centered in the western part of the WSA. Between Morgan Valley and Lake Berryessa, there have been numerous earthquakes. The largest magnitudes are between 2.0 and 3.0. At Knoxville, there have been five earthquakes with magnitudes less than 2.0. The seismicity of the Geysers-Clear Lake area, is discussed by Bufe and others (1981).

GEOLOGIC HISTORY

During late Jurassic through Late Cretaceous time, sediments of the Franciscan Complex and the Great Valley Sequence were simultaneously being deposited in parallel basins on oceanic crust. The rocks of the Franciscan Complex are interpreted to have been deposited in a trench over an east-dipping subduction zone located to the west of the fore-arc basin of



GEOLOGIC STRUCTURE MAP
OF MORGAN-WILBUR AREA

SCALE

Fault trace
Inferred fault trace
Placement contact
Anticlinal axis
Synclinal axis

Figure 3

the Great Valley Sequence. However, several lines of evidence presented by McLaughlin (1981) suggests this may be an over-simplification of the sequence of events. The Great Valley Sequence is interpreted to represent fore-arc basin deposits that were derived from the Klamath and Sierran Island arc terraines as a series of coalescing submarine fans. The source areas for the Franciscan sediments have been destroyed by subduction.

From Mid-Cretaceous time onward, the rocks of the Great Valley Sequence and Franciscan Complex were simultaneously deformed by underthrusting caused by sea floor spreading. Superposition of the two units was brought about by the thrust faults, whose position today is nearly everywhere marked by serpentine. Beneath the thrust, the Franciscan rocks are sheared and metamorphosed.

During Tertiary time shearing along the San Andreas fault system has produced a zone at least 60 Km wide, which was affected by accumulation of strain and creep on numerous subsidary fault zones. These faults, particularly those which trend northwest and north-northwest have provided major conduits for movement of thermal fluids to the surface (Hearn and others, 1981).

Following the deposition of the Cache Formation, the Coast Ranges experienced considerable uplift and deformation. Prior to the uplift, Cache Creek was contained in a wide valley or flood plain, which may have been at about the level of the Sacramento Valley during Pliocene and Pleistocene time (Lawton, 1956).

MINERAL RESOURCES

INTRODUCTION

Locatable minerals within the Wilderness Study Area (WSA) include mercury, gold, asbestos and chromite. In addition, adjacent to the area at Wilbur Springs to the north, at Knoxville to the south, at the Baker Mine to the southwest, and at Sulphur Bank to the west, gold-mercury ore has been reported (Becker, 1888). Mercury has been the primary metal sought at these mines, although gold was mined for several decades in the 1880s at Wilbur Springs. Recent development work at the Knoxville mines has delineated a major gold deposit which may extend into the WSA. Claims have been staked in the WSA to explore for this possible extension of the gold mineralization.

Oil, gas, and geothermal energy are leasable resources which potentially could occur in economic quantities. There are gas seeps within the WSA, and there are numerous oil and gas seeps at Wilbur Springs, and oil seeps are reported at Knoxville (Lawton, 1956, Averitt, 1945). There are hot springs at Wilbur Springs and Knoxville. At Wilbur Springs, it is believed that electric power could be generated. The hot water reservoir at Wilbur Springs may extend into the WSA.

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MINERAL RESOURCES

INTRODUCTION

Listable minerals within the Mitchness Study Area (MSA) include mercury, gold, antimony and chromite. In addition, antimony in the area at Wilbur Springs is the north, at Knoxville to the south, at the Bear Mine to the northwest, and at Sulphur Bank to the west. Gold-mercury ore has been produced (Decker, 1966). Mercury has been the primary metal sought at these mines, although gold was mined for several decades in the 1880s at Wilbur Springs. Recent development work at the Knoxville mines has delineated a major gold target which may extend into the MSA. Claims have been filed in the MSA to explore for this possible extension of the gold mineralization.

Oil, gas, and geothermal energy are leasable resources which potentially could occur in economic quantities. There are gas seeps within the MSA, and there are numerous oil and gas seeps at Wilbur Springs, and oil seeps are reported at Knoxville (Taylor, 1956, Merritt, 1967). There are hot springs at Wilbur Springs and Knoxville. At Wilbur Springs, it is believed that electric power could be generated. The hot water reservoir at Wilbur Springs may extend into the MSA.

HISTORY

Beginning in the early 1860s, discovery and subsequent development of mineral resources took place at Wilbur Springs and Knoxville. Mercury was discovered at Knoxville in 1862 while cutting a grade for a road. The mines were important producers until 1883. Production slacked, but mercury was produced almost every year since the opening of the mines until 1943 (the last year figures are available). Table 1 lists production from the mines in this area. Past production of mercury from the Knoxville mines is significant. Knoxville ranks third in the United States in terms of total mercury produced.

At Wilbur Springs, mercury was discovered in 1862 and production took place at the Abbott Mine between 1870 and 1890, and at other periods of high mercury prices. Gold was discovered at the Manzanita Mine in the early 1860s and reportedly was worked principally for gold until 1891, when mercury was also mined. Widely known oil and gas seeps near Wilbur Springs were the object of unsuccessful drilling in 1865-1866 (Carlson, 1962, p. 23).

MERCURY-GOLD MINERALIZATION

The recent discovery of a large, previously unsuspected quantity of gold at Knoxville (at last estimate 3.2 million ounces), is not the only known occurrence of gold with mercury (or antimony) in the Coast Range of California. The earliest and perhaps one of the most comprehensive studies of the mercury deposits of the Pacific Coast was that of Becker (1888). He determined the presence of gold at mercury mines at Wilbur Hot Springs, Sulphur Bank, as well as the Knoxville mines. He also reported the occurrence of gold at the Picacho Mine, located southwest of New Idria. Other workers (Bradley 1916, Newmont Exploration 1965, Bailey and Meyers 1949) have identified gold at the Calistoga, Oat Hill mines, and the Stayton District.

Although over 50 percent of the largest mercury deposits in the Coast Range are associated with altered serpentine, mercury also occurs in rocks of the Franciscan and Knoxville Formations, as well as Tertiary volcanic rocks and at active hot springs. The rock type does not appear to be the controlling factor in the deposition of mercury in this area.

The presence of young high-angle faults appears to be the most important factor in the location of mercury deposits. All mercury deposits are associated with faults and fracture zones in this area. Averitt (1945) suggested that clay gouge zones effectively channeled mineral bearing water and this controlled deposition at the Knoxville mine.

The origin of the mercury, gold, hydrocarbons and the water, which acted and still acts as a transporting medium, are all intimately associated with the marine sediments. In a study of thermal and mineral waters in

HISTORY

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HEXAVALENT MINERALIZATION

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Although over 90 percent of the largest mercury deposits in the Coast Ranges are associated with altered serpentine, mercury also occurs in rocks of the Franciscan and Knoxville formations, as well as Tertiary volcanic rocks and at active hot springs. The rock type does not appear to be the controlling factor in the deposition of mercury in this area.

The presence of young mid-Cenozoic faults appears to be the most important factor in the location of mercury deposits. All mercury deposits are associated with faults and fracture zones in this area. Averitt (1945) suggested that clay gouge zones effectively channeled mineral bearing water and this controlled deposition at the Knoxville mine.

The origin of the mercury, gold, hydrocarbons and the water, which acted as both a transportation medium, and as a chemically reactive agent with the mineral constituents. In a study of thermal and mineral waters in

Year	Knoxville (Excelsior, Redington, Boston)	Reed (California, Andalusia)	Manhattan (Lake)	Red Elephant	Harrison (New England, Ruby, Grizzly, January)	Total[3]	Average price of quicksilver per flask
1860	----	----	----	----	----	-----	53.55
61	----	----	----	----	----	-----	42.05
62	444	----	----	----	----	444	36.35
63	852	----	(a)	----	----	852	42.08
64	1,914	----	(a)	----	----	2,714	45.90
65	3,545	----	(a)	----	----	3,545	45.90
66	2,254	----	(a)	----	----	2,254	53.13
67	7,862	----	(a)	----	----	7,862	45.90
68	8,686	----	(a)	----	----	9,808	45.90
69	5,018	----	(a)	----	----	6,598	45.90
1870	4,546	(b)	(a)	----	----	6,766	57.38
71	2,128	(b)	(a)	----	----	4,098	63.10
72	3,046	(b)	(a)	----	----	4,876	65.93
73	3,294	995	(a)	----	----	5,249	80.33
74	6,678	1,500	(a)	----	----	8,323	105.18
75	7,513	1,500	437	----	----	9,453	84.15
76	9,183	965	976	----	----	12,309	44.00
77	9,399	1,516	439	----	----	11,354	37.30
78	6,686	1,640	----	----	----	8,326	32.90
79	4,516	1,110	----	----	----	5,626	29.85
1880	2,139	422	----	----	----	2,561	31.00
81	2,194	----	----	----	----	2,194	29.83
82	2,171	----	----	----	----	2,171	28.23
83	1,894	----	----	----	----	1,894	28.75
84	881	----	(c)	----	----	881	30.50
85	385	----	----	----	----	385	30.75
86	409	----	----	----	----	409	35.60
87	673	----	----	----	----	673	42.38
88	126	----	----	----	----	126	42.50
89	812	----	----	----	----	812	45.00
1890	505	----	----	----	----	505	52.50
91	442	----	----	----	----	442	45.25
92	728	----	612	----	----	728	40.71
93	1,012	----	578	----	----	1,012	36.75
94	1,200	----	----	----	----	1,200	30.70
95	163	----	455	----	----	618	37.04
96	1,906	----	598	----	----	2,504	34.96
97	1,550	----	453	----	----	2,003	37.28
98	1,012	----	790	----	----	1,802	38.23
99	882	----	542	----	----	1,424	47.70
1900	816	----	----	----	(e)	816	44.94
01	1,545	----	400	----	----	1,945	48.46
02	1,950	----	317	----	----	2,267	43.20
03	1,730	----	284	----	----	2,014	42.25
04	913	----	399	----	----	1,312	37.62
05	223	----	250	----	----	473	35.94
06	----	----	----	----	----	-----	36.50
07	100	----	----	----	----	100	38.16
08	100	----	----	----	----	100	42.33
09	17	----	----	----	----	17	47.71
1910	33	----	----	----	----	33	45.23
11	140	----	----	----	----	140	46.01
12	287	----	----	----	----	287	42.04
13	287	(d)	----	----	----	287	40.23
14	77	15	----	----	----	92	49.05
15	58	14	----	----	----	72	81.52
16	60	----	46	----	----	108	93.50
17	42	14	----	----	13	69	98.29
18	----	----	----	----	30	30	114.03
19	----	----	----	----	220	220	89.04
1920	----	----	----	----	----	-----	75.45
21	----	----	----	----	----	-----	44.56
22	68	----	----	----	----	68	55.35(f)
23	----	----	----	----	----	-----	60.98
24	----	----	----	----	----	-----	68.33
25	----	----	----	----	----	-----	80.81
26	----	----	----	----	----	-----	87.64
27	38	----	9	----	----	47	111.67
28	541	----	----	----	----	541	118.84
29	742	----	----	74	----	816	117.78
1930	970	----	----	154	----	1,124	110.36
31	649	5	----	90	----	744	83.22
32	13	2	1	----	----	16	52.30
33	21	----	3	----	----	24	55.94
34	74	----	----	15	----	89	67.22
35	38	----	----	16	----	54	67.23
36	12	----	2	----	2	16	76.62
37	----	----	131	----	28	159	90.18
38	----	----	72	----	28	100	75.47
39	----	4	33	----	14	51	103.94
1940	75	467	51	----	10	603	176.87
41	458	784	33	----	----	1,275	185.02
42	600	2,422	31	56	(d)	3,109	196.35
43	642	1,771	26	----	(d)	2,439	195.21
Total	121,967	15,146	11,562	405	345	156,458	

[2] 76.5 lbs. previous to June 1904; 75 pounds from June 1904 to January 1928; and 76 pounds since January 1928.

[3] Includes flasks of unknown origin before 1877.

(a) Manhattan production between 1863 and 1875 totaled 3,594 flasks.
(b) Amount of production unknown.
(c) Intermittent unrecorded production between 1884 and 1892.
(d) Small unrecorded production.
(e) Pre-1900 production small and unrecorded.
(f) Tariff Act of 1922 placed import duties of $18.75 per flask.

Table 1—Production record of mines in Knoxville quicksilver district 1862-1943[1] *(in flasks)*[2]

the Clear Lake area, White and others (1973) concluded that the high-chloride connate waters found at Wilbur Springs are chemically and isotopically similar to the oil-field waters of the Central Valley of California, but are generally enriched in bicarbonates and boron. This water probably evolved from compaction and loss of pore water in the marine sediments, but is also affected to some extent by continuing low-grade metamorphism at depth.

Hydrocarbons present at Wilbur Springs and Knoxville are common in many of the mercury mines in this region and came to the surface in the same fractures that hot mineral laden water did. At Wilbur Springs, hot water and hydrocarbons (oil and gas) are ascending in the same fracture system.

Moisseeff (1966) concluded that the mercury at Wilbur Springs probably was concentrated from sediments in "solutions of metamorphic or connate origin." Although Barnes and others (1973) concluded that fluids presently discharged at Wilbur Springs could not have formed the quantity of mercury deposits there, since the concentration in the water is not high enough to account for the amount of mercury deposited since Tertiary time (?).

It is likely that the gold has a similar origin as the mercury. Steve Graham (personal communication, July 30, 1981), noting the lack of flour gold in gold-bearing gravels in the Sierras, sampled the Great Valley Sequence (and younger formations) in the spring of 1981, hoping to detect the timing of gold emplacement in the Sierras. He noted a general increase in gold with decrease in age. Knoxville Formation assayed .001-.002 oz. per ton, and the Eocene formations assayed .006-.008 oz. per ton. The high chloride content of the water may have facilitated in the transportation of gold, since in hydrothermal solutions in general gold is transported as the aurous chloride complex $AuCl_2$ (Radtke and Scheiner, 1970).

In the structurally complex Coast Range, several volcanic fields (Sonoma, Tolay, Berkely Hills, Quien Sabe, Neenach-Pinnacles) have erupted, generally decreasing in age northward. The Clear Lake volcanic field is the youngest and most northerly of these fields. Within the Clear Lake volcanic field, isotopic ages and the eruptive sequence also show a general decrease in age northward from 2 m.y. in the south to about 10,000 years in the north. The Geysers geothermal area is believed to be heated by a silicic magma body centered below 10 km in depth, the top of which is within 7 km of the surface (Hearn, and others 1981). On the basis of a detailed gravity study, a series of 100 m temperature gradient holes, and two deep wells (400 m and 1,200 m), Harrington and Verosub (1981) concluded that presumably the source of heat at Wilbur Springs is a deep magma intrusion. Fractures provide the porosity needed to transfer the heat in the form of hot water or steam from the intrusion.

The chemistry of mercury at the Wilbur Springs deposits has been studied in detail by Moisseeff (1966) and is beyond the scope of this paper. The geochemistry of the gold in these mines or the Knoxville mines is currently unknown. However, there are some conspicuous similarities between these deposits and the Carlin-type gold deposits which have become the source of large quantities of gold mined in Nevada.

the Clear Lake area, Weiss and others (1972) concluded that the high chloride connate waters found at Wilbur Springs are chemically and isotopically similar to the oil-field waters of the Central Valley of California, but are generally enriched in bicarbonates and boron. This water probably evolved from compaction and loss of pore water in the marine sediments, but is also affected to some extent by continuing low-grade metamorphism at depth.

Hydrocarbons present at Wilbur Springs and Knoxville are common in many of the mercury mines in this region and come to the surface in the same fractures that hot mineral laden water did. At Wilbur Springs, hot water and hydrocarbons (oil and gas) are escaping in the same fracture system.

Rytuba (1976) concluded that the mercury at Wilbur Springs probably was concentrated from geothermal "solutions of meteoric or connate origin." Although Barnes and others (1973) concluded that fluids presently discharged at Wilbur Springs could not have formed the quantity of mercury deposits there, since the concentration in the water is not high enough to account for the amount of mercury deposited since Pleistocene time (?).

It is likely that the gold has a similar origin as the mercury. Steve Evans (personal communication, July 30, 1981), noting the lack of fluorspar in gold-bearing gravels in the Sierra, sampled the Great Valley, Sierra (and Franciscan formations) in the spring of 1981, hoping to detect the timing of gold emplacement in the Sierra. He noted a general increase in gold with decreasing age. Knoxville formation assayed .001-.002 oz./cu. yd., and the Cosumnes formation assayed .005-.008 oz. per ton. The high chloride content of the water may have facilitated in the transportation of gold, since in hydrothermal solutions in general gold is transported as the aqueous chloride complex $AuCl_2^-$ (Rytuba and Schulmer, 1979).

In the structurally complex Coast Range, several volcanic fields (Sonoma, Clear Lake, Geysers, Wilbur Springs, Monarch-Pinnacles) have erupted, generally decreasing in age northward. The Clear Lake volcanic field is the youngest and most northerly of these fields. Within the Clear Lake volcanic field, isotopic ages and the magnetic sequence also show a general decrease in age northward from 2 m.y. in the south to about 10,000 years in the north. The Geysers geothermal area is believed to be heated by a pluton more than 10 km in depth. The top of which is within 7 km of the surface (Isaac, and others 1981). On the basis of a detailed gravity study, a cavity of 100 m temperature gradient holes, and two deep wells (800 m and 2,200 m), Herrington and Verzuh (1981) concluded that presently the source of heat at Wilbur Springs is a deep magma intrusion. Fractures provide the porosity needed to transfer the heat in the form of hot water or steam from the intrusion.

The chemistry of mercury at the Wilbur Springs deposits has been studied in detail by Rytuba (1980) and is beyond the scope of this paper. The potentiality of the gold in these mines or the Knoxville mines is contentously unknown. However, there are some contributors speculating that these deposits and the Carlin-type gold deposits which have become the source of large quantities of gold mined in Nevada.

Radtke and other workers (see Boyle, 1980, for a summary) have done the pioneer work on the Carlin-type deposits. From their work a checklist of geologic, mineralogic, and geochemical features common to these type of deposits has been developed. This list includes: silty carbonate rocks; the presence of hydrocarbons; gold associated with mercury, arsenic, antimony and thallium; replacement by fine-grained silica and minor pyrite, and; mineralization related with strong normal faults. Fluids at these deposits have been shown to be of meteoric origin. Work by Radtke and Scheiner (1970) suggest the presence of carbonaceous materials (hydrocarbons) may be critical for the deposition of gold.

In the Coast Ranges, mercury deposits are largely but not entirely, restricted to serpentine which has been replaced by silica and carbonate. Hydrocarbons and pyrite are very common in these deposits. The presence of the hydrocarbons supports the findings of White and others (1973) that the water which transported the mercury is of connate origin, and that the silty sediments of the Great Valley Sequence is the source. This water, therefore, has a different source than the Carlin-type deposits. Gold is associated with mercury and/or antimony in the Coast Ranges. Although on Red Mountain, southeast of Ukiah, gold is instead associated with copper. The mercury deposits of the Coast Ranges are late Tertiary to Quaternary in age. They are also associated with strong normal faults.

From this discussion, it can be seen that there are numerous similarities between the mercury deposits in the Coast Ranges of California and the Carlin-type gold deposits. The Knoxville gold deposit is the first major deposit of this type to be recognized in California. However, it is clear that there is potential for others.

MERCURY-GOLD DEPOSITS IN ADJACENT AREAS

In the Knoxville district, mercury deposits are confined to silica-carbonate rocks along northwest-trending faults, between the contact of serpentine and Knoxville sediments. The Manhattan mine is an exception, with mercury ore occurring in altered Tertiary olivine basalt and tuff. Minerals reported from these mines include cinnabar, metacinnabar, pyrite, marcasite, stibnite, native mercury, copper oxides, gold, millerite (nickel sulfide) and redingtonite (hydrous chromium sulfate). Pyrite in the district shows traces of gold (Averitt, 1945, p. 78). Apparently minor leaching has occurred, yielding free gold as reported by Becker (1888, p. 282):

> The surface soil here (the Manhattan mine) and also near the Redington (Knoxville) mine contains cinnabar, resulting from the erosion of croppings, and accompanying the cinnabar is free gold, which may be found by panning the soil.

At Wilbur Springs, mercury ore occurs in the same localities as the hot springs. Three groups of mines can be recognized in the vicinity of Wilbur Springs. The Wilbur Springs Group consists of the Wide Awake, Central and Empire mines located along a "dike" of detrital serpentine, and the Manzanita and Cherry Hill mines located in fractured sedimentary

Radtke and other workers (see Doyle, 1968, for a summary) have done the primary work on the Carlin-type deposits. From their work a checklist of geologic, mineralogic, and geochemical features common to these type of deposits has been developed. This list includes: silty carbonate rocks; the presence of hydrocarbons; gold associated with mercury, arsenic, antimony and thallium; replacement by fine-grained silica and minor pyrite; and, mineralization related with strong normal faults. Fluids at these deposits have been shown to be of meteoric origin. Work by Radtke and Scheiner (1970) suggest the presence of carbonaceous materials (hydrocarbons) may be critical for the deposition of gold.

In the Nevada ranges, mercury deposits are largely but not entirely, restricted to carbonate which has been replaced by silica and carbonate. Hydrocarbons and pyrite are very common in these deposits. The presence of the hydrocarbons supports the findings of White and others (1967) that the water which transported the mercury is of connate origin, and that the silty sediments of the Great Valley Sequence is the source. This water, therefore, has a different source than the Carlin-type deposits. Gold is associated with mercury and/or antimony in the Coast Ranges. Although on Red Mountain, southwest of Ukiah, gold is instead associated with copper. The mercury deposits of the Coast Ranges are late Jurassic to Quaternary in age. They are also associated with strong normal faults.

From this reconnaissance, it can be seen that there are numerous similarities between the mercury deposits in the Coast Ranges of California and the Carlin-type gold deposits. The Moxyville gold deposit is the first deposit of this type to be recognized in California. However, it is clear that there is potential for others.

MERCURY-GOLD DEPOSITS IN ADJACENT AREAS

In the Moxyville district, mercury deposits are confined to silica-carbonate rocks along northwest-trending faults, between the contact of serpentine and Moxyville sediments. The Manhattan mine is an exception, with rocks are occurring in altered Jurassic silty to fine sandstone. Mercury deposits can occur in these mines include cinnabar, metacinnabar, pyrite, calcite, native mercury, copper oxides, gold, realgite (hydrat realgite) and realgitonite (hydrous arsenium sulfide). Pyrite is the district where trace of gold (Averitt, 1958, p. 78). Quantrell mine, Lancaster has occurred, yielding free gold as reported by Becker (1888, p. 282):

> The surface soil here (the Manhattan mine) and also that in the division (Moxyville) mine contains cinnabar, resulting from the action of circulation, and attacking the cinnabar is free gold, which may be found by panning the soil.

At Wilbur Springs, mercury has occurs in the same localities as the hot springs. These deposits of mines can be recognized in the vicinity of Wilbur Springs. The mining sections focus consists of the mine Knight, Central and Sulphur mines located along a "line" of detrital serpentine, and the Sunshine and Cherry Hill mines located in fractured sedimentary

rocks of the Knoxville Formation. The Elgin Group occurs in a body of silicified serpentine. The Clyde mine about a mile to the northwest, is at the contact of serpentine and the Knoxville formation. The Abbott Group includes the Boggess, Abbott and Turkey Run mines, which are located in silica-carbonate rock at the contact between the serpentine with Knoxville sediments. Minerals present in the Wilbur Springs district include cinnabar, metacinnabar, pyrite, marcasite, gold, and minor calomel.

Gold occurs at the Cherry Hill, Manzanita, Abbott, and Clyde mines (Logan, 1929). At the Abbott mine, traces of gold are present in the marcasite (Moisseeff, 1966, p. 85). Becker (1888, p. 367) noted the ore at the Manzanita mine consisted of:

> ...cinnabar and gold, which are sometimes in direct contact, and some metacinnabarite. These minerals are accompanied by pyrite and marcasite, chalcopyrite, stibnite, calcite, and quartz. The gold is often visible in feather-like, crystalline aggregates, sometimes in direct contact with cinnabar and sometimes deposited directly upon calcite....

At this mine, Moisseeff (1966) described the occurrence of gold as specks or "sheets" in leached zones. The destruction of iron sulfides probably liberated the gold which then became scattered in the leached zones.

MERCURY-GOLD WITHIN THE WSA

The Shamrock mine situated in Sec. 23, 14T.13N.,R.6W.MDM was located and worked prior to 1903 (Forstner, 1903). In 1927 and 1935, Orville Blevins of Redding produced mercury from the property. Foyle Mason, acquired the property in the early 1940s and held it until his death in 1980. Mason did not produce any mercury from the property. In 1968, M.C. Smith and the late Kay Miller, both of Redding, located the Deep Shaft and Zodiac claims over Mason's claims (the Shamrock and Merle) apparently with his permission. Smith and Miller erected a mill at the expense of $100,000 and have produced a "couple of hundred" flasks of mercury. They determined the presence of gold on these claims, but were more interested in the mercury.

The Hunting Fault, which separates serpentine on the south from sediments of the Great Valley Sequence on the north, trends northwest across the Deep Shaft and Zodiac claims. The fault zone is expressed as a red clay gouge zone that contains sparce mercury values. The most significant mercury mineralization occurs in serpentine which is altered to opalite, located south of the fault. The altered serpentine is mineralized with cinnabar, copper oxides, pyrite, and gold. Small amounts of gold have been recovered from the ore by the use of a shaker table. Placer gold, and a nugget which weighed 0.25 ounces have been recovered from Rocky Creek. Reportedly, cinnabar crystals were found to have grown within one gold nugget (M.C. Smith personal communication, August 25, 1981).

rocks of the Knoxville formation. The Elgin group occurs in a body of altered serpentine. The Clyde mine about a mile to the northwest, is at the contact of serpentine and the Knoxville formation. The Abbott mine lies about the Boggess, Abbott and Turkey Run mines, which are located in silica-carbonate rock at the contact between the serpentine with known wide sediments. Minerals present in the Wilbur Springs district include cinnabar, metacinnabar, pyrite, marcasite, gold, and minor calomel.

Gold occurs at the Cherry Hill, Manzanita, Abbott, and Clyde mines (Logan, 1929). At the Abbott mine, traces of gold are present in the marcasite (Morrison, 1948, p. 89). Becker (1888, p. 357) noted the ore at the Manzanita mine consisted of:

> ...cinnabar and gold, which are sometimes in direct contact, and some metacinnabarite. These minerals are accompanied by pyrite and marcasite, chalcopyrite, stibnite, realgite, and orpiment. The gold is often visible in leaflet-like, crystalline aggregates, sometimes in direct contact with cinnabar and sometimes deposited directly upon realgite....

In this mine, Whitney (1866) described the occurrence of gold as "shoots" in leached zones. The destruction of iron sulfides probably liberated the gold which then became scattered in the leached zones.

HERCULES-GOLD within the WCA

The Sunrock mine situated in Sec. 25, T41.1N.,R.8W.MDM was located and worked twice, in 1903 (Fortuner, 1903). In 1927 and 1935, Orville Wirth of Redding produced mercury from the property. Foyle Mason, acquired the property in the early 1940s and held it until his death in 1960. Mason did not produce any mercury from the property. In 1964, Mr. Smith and the late Ray Miller, both of Redding, located the Gold Cart and Jodie claims over Mason's claims (the Sunrock and Hercules) apparently with the permission of Mr. Miller produced a mill at the expense of $100,000 and have produced a Florida of Inverness flasks of mercury. They determined the presence of gold on these claims, but were more interested in the mercury.

The Trinity Fault, which separates serpentine on the south from sediments of the Great Valley sequence on the north, trends northwest across the Sunrock and Jodie claims. The fault zone is exposed as a red clay gouge zone that contains sparse mercury values. The most significant mercury mineralization occurs in serpentine which is fractured in quantity, located south of the fault. The mineral serpentine is associated with cinnabar, copper, calcite, pyrite, and gold. Small amounts of gold have been recovered from the pit by the use of a shaker table. Placer gold, and a nugget weighing approximately 0.22 ounces, has been recovered from nearby. Cinnabar crystals were found to have been mined with the gold nugget (M.C. Smith, oral communication, August 23, 1983).

In the southeastern end of the WSA, claims have been located in Sections 14, 15, 22 and 23 T.12N., R.6W. and Sections 7, 18 and 19 T.12N., R.5W.MDM. These claims were located on the periphery of the recently discovered immense gold deposit at Knoxville.

CHROMITE

Placer chromite occurs east of Deadman Canyon in Sections 7 and 13 T.13N., R.6W. (Brice, 1953).

ABESTOS

Asbestos has been prospected north of Brushy Sky High in the SE 1/4 of Section 34 T.13N., R6W.MDM. Here, a chrysotile vein trends N.44°E. and dips 52°W in highly sheared serpentine. The vein is 18 inches wide at the point of discovery and pinches to 6 inches within 100 feet along strike. The asbestos fibers average an eighth of an inch long and are slightly brittle. In 1952, soil was removed with a bulldozer and prospect trenches were cut at four points across the vein (Brice, 1953 p. 60).

GEMSTONES

Jasper cobbles are common along Cache Creek (Brice, 1953).

MAGNESITE

Magnesite of probably minor quantities occurs at the Shamrock mercury mine (Foyle Mason mining claim file CAMC 49164).

GRAVEL

Gravel deposits along the north fork of Cache Creek from Upper Wilson Valley to the confluence with Long Valley Creek have potential for use in concrete aggregate (Klein and Goldman, 1958).

OIL AND GAS

Five oil seepages in the Wilbur Springs area have prompted the drilling of five shallow wells on the Wilbur Springs Anticline between 1844 and 1937. All of the wells were less than 3,000 feet deep. None of these wells has resulted in commercial production, but there

In the southeastern one of the WSM, claims have been located in Sections 24, 13, 22 and 23 T.12N., R.6W. and Sections 6, 18 and 19 T.12N., R.5W.WSM. These claims were located on the periphery of the recently discovered Hansen gold deposit at Wrangellia.

CHROMITE

Placer chromite occurs east of Deadman Canyon in Sections 7 and 13 T.12N., R.4W. (Grice, 1952).

COBALT

Cobalt has been prospected north of Grizzly Bluff in the SE 1/4 of Section 34 T.12N., R5W.WSM. Here, a chrysotile vein trends N.44°E. and dips 32°W in highly sheared serpentine. The vein is 18 inches wide at the point of discovery and pinches to 6 inches within 100 feet along strike. The asbestos fibers average an eighth of an inch long and are slightly brittle. In 1952, trench was trenched with a bulldozer and crosscut trenches were cut at four points across the vein (Grice, 1952 p. 60).

COPPER

Copper carbonates are common along Cache Creek (Grice, 1952).

MAGNESITE

Magnesite of probably minor quantities occurs at the Chromrock mercury mine (Coyle Mason mining claim File CMM 4(9)6A).

GRAVEL

Gravel deposits along the South Fork of Cache Creek from Lower Hilton Valley to the confluence with Long Valley Creek have potential for use in concrete aggregate (Klein and Coleman, 1959).

OIL AND GAS

Five oil seepages in the Willow Springs area have prompted the drilling of five shallow wells on the Willow Springs Anticline between 1901 and 1937. All of the wells were less than 3,000 feet deep. None of these wells has resulted in commercial production, but there

have been shows of oil in several of them (Lawton, 1956, p. 211). At the Reed Mine, north of Knoxville, Averitt (1945, p. 87) observed oil seeps.

Within the Cache Creek area gas seeps were observed by Lawton (1956, p. 194):

> ...where the Wilson fault crosses Cache Creek just south of Section 21, T.13., R.5W. Sulfurous springs are also common in this area.

Lawton (op. cit., p. 214) considered the Cache Creek area one of the most promising in the area of his thesis for the entrapment of oil. He stated:

> In the southcentral portion of the area, in parts of Section 16, 17, 18, 20 and 21, T.13N., R.5W., the gentle folding and the Dunfield, Wilson and Kennedy Faults may form a structural trap. Drilling objectives here would be the Leesville member of the Little Valley formation, the Blue Ridge member of the Crack Canyon Formation, and the sandstone and conglomerate horizons in the Sulfur Creek (=? Knoxville) Formation. This is one of the most promising structures in this area as it is large and the bounding faults and the gentle folding are well defined. The best well location might be in the center of Section 21, T.13N., R.5W.

GEOTHERMAL ENERGY

The Wilbur Springs geothermal area has the potential to generate electric power (Higgins and Martin, 1980). A series of shallow temperature gradient holes indicate thermal gradients as high as .3°C/m, and two deep holes drilled to 400 m and 1,200 m reached maximum bottom temperatures of 120°C and 140°C respectively. Harrington and Verosub (1981) studied the Wilbur Springs area, and concluded that the geothermal reservoir, supplying heat for the hot springs continues south of Highway 20 in the vicinity of Destanella Flat. This is about one mile from the WSA.

Very little is known about the geothermal potential of the Knoxville KGRA. There is a 22°C warm spring at Knoxville.

have been shows of oil in several of them (Lewton, 1956, p. 211). At the Hines Mine, north of Knoxville, Averitt (1954, p. 87) observed oil seeps.

Within the Cache Creek area gas seeps were observed by Lewton (1956, p. 194):

> ...where the Wilson fault crosses Cache Creek just south of Section 22, T.13N., R.5W. Solfatara springs are also common in this area.

Lewton (op. cit., p. 24) considered the Cache Creek area one of the most promising in the area of his thesis for the entrapment of oil. He stated:

> In the southeastern portion of the area, in parts of Section 16, 17, 19, 20 and 21, T.13N., R.5W., the gentle folding and the Knoxville, Wilson and Kennedy faults may form a structural trap. Drilling objectives here would be the Lonsville member of the Little Valley Formation, the Blue Ridge member of the Creek Canyon Formation, and the sandstone and conglomerate horizons in the Sutter Creek (=? Knoxville) Formation. This is one of the most promising structures in this area as it is large and the Kennedy fault and the gentle folding are well defined. The best well location might be in the center of Section 21, T.13N., R.5W.

GEOTHERMAL ENERGY

The Wilbur Springs geothermal area has the potential to generate electric power (Higgins and Martin, 1980). A series of shallow temperature gradient holes indicate thermal gradients as high as 1.2°C/m, and two deep holes drilled to 400 m and 1,200 m reached maximum bottom temperatures of 120°C and 140°C respectively. Harrington and Warren (1981) studied the Wilbur Springs area, and concluded that the geothermal resource, supplying heat for the hot springs, could be developed economically. Length of highway 20 in the vicinity of Lower Lake, Wilbur Springs and Williams are also from the USA

Very little is known about the geothermal potential of the Knoxville area. There is a 55°C water spring at Knoxville.

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